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ASTRONOMY AND ASTROPHYSICS

On correlations between diffuse interstellar bands

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Abstract. One way to better apprehend the problem of diffuse interstellar bands (DIBs) is to search for correlations between the bands in a large sample of spectra towards various lines of sight: a strict correlation may imply that a common carrier is at the origin of the bands, whereas a non-correlation means that different species are involved. We propose this observational test for 10 DIBs collected in up to 62 Galactic lines of sight. Strong DIBs do not strictly correlate, and sometimes the correlation is very poor. Only one example of a strict correlation has been found in our sample between the DIBs at 6614 and 6196 Å, that could significate a single carrier for those two bands. The general absence of strict correlations is discussed in the context of molecular carriers for the DIBs.

Key words: interstellar medium–extinction–molecules–absorption bands

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1. Introduction

Since the first characterization of a visible diffuse band as an interstellar feature by Merill (1936), the observational study of DIBs has made much progress. However, no certain DIB identification has occured from that time (Herbig 1995 and Snow 1995). The present tendency is to gather the DIBs into subclasses, or families, of common properties. Chlewicki et al. (1986, 1987) and Krełowski & Walker (1987) have made the first attempts to build DIB families. Inside a family, the intensity ratios of DIBs should be constant (Miles & Sarre, 1993). At that time, only a few bands were classified, and these correlations rely on poor statistics. A more extensive correlation study has been recently published (Cami et al. 1997).

As the idea that the carriers were molecular was progressively adopted (Léger and d'Hendecourt 1985, Crawford et al. 1985, Fulara et al. 1993), it became clear that the observed DIB spectrum could be a mixture of vibronic states of a large, but not infinite, number of molecular species. Therefore, the strength ratio of any two DIBs originating in the same molecule should be identical along any sightline. In such a case we must observe a very tight correlation, all the scatter resulting only from the observational uncertainties. However, an observed strict correlation is not the proof of a single carrier, as very close species can also be invoked (i.e. species in which abundances have exactly the same behaviour). Finally, a non-correlation between two DIBs undoubtly implies that they are not carried by the same species.

The goal of the present paper is to use a large sample of echelle spectra acquired at the Mc Donald and Pic du Midi Observatories, to survey the correlations between a few DIBs. The strong DIBs at 4430, 5780, 5797, 5850, 6196, 6234, 6270, 6284, 6379 and 6614 Å are surveyed in 11 to 62 lines of sight.

2. The observational material

Our observational material originates from two distinct samples, taken at Mc Donald and Pic du Midi Observatories.

Mc Donald observations made use of the Cassegrain echelle spectrograph, installed at the 2.1m telescope (Krełowski & Sneden, 1993). The spectra are at a resolution of 60,000 over the range 5600 – 7000Å and of especially high S/N ratio – usually 500 or more. The DIBs at 5780, 5797, 5850, 6379 and 6614 Å are measured in 50 stars, and the DIBs 6234, 6270 and 6284 Å are measured in 36 stars.

Pic du Midi observations have been performed with the aid of the 2.03m Bernard Lyot Telescope in July 1995 and February 1996. The instrument used is the echelle spectrograph MUSICOS (Baudrand & Böhm, 1992). Within two exposures, it allows coverage of the whole visible range (3850-8750 Å) at a resolving power of 40,000. 46 orders in the "blue" range (3850-5400 Å) and into 44 orders in the "red" range (5100-8750 Å) compose the whole spectrum. We performed some redundancy with the previous measurement sample, and added 12 lines of sight. Also the 4430 Å DIB was measured in these spectra.

To separate the orders and correct them for the Blaze distortion we used the data reduction software developped for MUSICOS by T. Böhm and J-F. Donati (private communication). The wavelength calibration is provided by a Thorium-Argon lamp. A tungsten lamp is used to flat-field the spectra. The order extraction is of good quality and allows the easy merging of individual orders to build broader spectral ranges. As an example, the merging of the orders near the broad 4430 Å feature is shown in Fig. 1, which was obtained by multiplying the flux in separate orders by a constant.

Table 1 characterizes our sample of target stars. The stars are bright ($m_v < 7$) and nearby, increasing the probability that they are obscured by a single cloud. A few highly reddened stars are also present, to see how the correlation plots extrapolate to high color excesses. However, these targets may have overlapping features which create confusion and we will rely more on low-reddened stars, unlike most previous DIB surveys.

The reddened stars have been observed together with some standards to separate the interstellar features from stellar and telluric contamination.

3. Measurements of the DIB strengths

The central depths of the interstellar diffuse features considered in this paper have been measured and tabulated in Table 2. The standard error was estimated by multiple measurements. It originates mostly from the continuum setting. We chose to list only the central depths (CD) of the features because they are less sensitive to contamination than equivalent widths (EW). For the broad features such as 4430 Å the profile is free from stellar contamination only in the spectra of extremely hot stars. For this reason, we used the spectrum of the O6 star HD210839 as a typical profile. This model spectrum was scaled to fit the observed bands, when contaminated by stellar lines. The 5780 and 5797 Å DIBs are measured with a low uncertainty due to their strength (Krełowski & Sneden 1993). The 5850, 6234 and 6270 Å DIBs are shallow and their measurements thus suffer a larger uncertainty. The 6284 Å band is blended by the atmospheric α band of molecular oxygen which limits the precision of measurement. The narrow 6196, 6379 and 6614 Å DIBs are free of any contamination and their depth can be determined quite precisely.

We checked that in most cases the bandwidth variation was negligible in the correlation plots. This means that the correlation in central depths reflects well the correlation in EW. It may differ in the cases where the bandwidth is affected by special effects such as a strong rotational broadening, named the “rocket effect” (Rouan et al. 1997, Lecoupanec et al. 1999). This effect should only be observed in strongly irradiated environments and is expected for large molecular carriers.

4. Discussion

4.1. Correlation analysis

We first checked the correlation degree between our DIB measurements and E_{B-V}. A weak correlation is observed, which is usually interpreted by the differing behaviours of DIB carriers and grains (responsible for the reddening). The moderate correlation between DIB intensities and color excess is the reason why we chose to plot correlation diagrams directly in DIB central depths CD rather than in CD/E(B-V). This also offers the advantage that the error bars are not enhanced by the uncertainty in E(B-V).

For correlation plots of each DIB pair we calculated the best fit linear curve. As an objective estimate of the correlation level, we used the Kolmogorov-Smirnov test (Peacock 1983). For each point we measured the distance to the best fitted line and we plotted the cumulative probability of this distance to be smaller than a given value. In the case of a strict correlation, this curve follows the law $\int exp(-2x^2)dx$ (Kolmogorov curve). The Pearson correlation coefficient is also calculated, which takes into account the error bars:

$$R = \frac{Cov(B1, B2)}{\sqrt{Var(B1)Var(B2))}} * \frac{1}{\sqrt{(1 + \frac{Var(E1)^2}{Var(B1)^2})(1 + \frac{Var(E2)^2}{Var(B2)^2})}}$$

where B1, B2, E1 and E2 are respectively the values of the measurements and their error bars. Error bars on the correlation coefficients are deduced by adding the contribution of each measurement and its variance. We normalised the coefficients to the largest sample of stars (62 elements), so that it takes into account the variability of the correlation due to the different samples used. The correlation coefficients are listed in Table 3. For the DIBs at 6270, 6234, and 6284 Å, 36 lines of sight are measured, while for the 4430 Å DIB, only 11 stars are considered. For these case, more measurements would be necessary to know the strength of the correlation at the same confidence level than for the other pairs of DIBs.

We observe roughly three degrees of correlation: i) 29 couples show a non correlation with low coefficient (roughly R < 0.7) (Fig. 2), ii) 15 couples show a rather good correlation (0.7 < R <

0.95) (Fig. 3), and iii) one couple shows a strong correlation: the pair 6196/6614 (R > 0.95) (Fig. 4).

4.2. Weak and medium correlations

The worst correlations are observed for the pairs of DIBs: 5850/5780, 6284/6379, 6614/5850, 6196/5850, 5797/6284 (some examples are shown in Fig. 2). For these cases, as for all correlations where R < 0.7 (Tab. 3), we can state that the DIBs do not originate from the same carrier and also that the carriers have distinct behaviour with respect to the physycal conditions. The observation that **usually one strong DIB corresponds to a single species** is thus for the first time confirmed on a strong statistical basis. Also the correlations with a weaker statistical basis have obviously a lower coefficient, as for the 4430 Å DIB.

The second level of correlation (Fig. 3) exists for instance between the DIBs at 5780 and 6284 Å. The correlation coefficient is higher, but it is obvious that a few points are more than 3σ far away from the best fitted line. This degree of correlation corresponds to the already proposed "families" (*e.g.* in Krełowski and Walker 1987). Also, Jenniskens et al. (1993) state that 5780 and 6284 DIBs behave similarly in Orion, and that they could both be linked to the neutral gas. The presence of similar substructures inside both features was also interpreted as a possibility of a single carrier (Jenniskens and Désert 1993). But later it has been remarked that some lines of sight show very discrepant band ratios (Krełowski and Sneden 1993).

As for this example, we observe many rather good correlations, corresponding to close species but obviously different molecules between the DIBs at 5797/5850, 5780/6614, 5780/6196, 5797/6614, 5797/6196, 6234/6196, 6379/6196, 6614/6270, 6284/6270. Note that usually these pairs of DIBs are of similar bandwidths, but this is not systematic. It is in agreement with the previous statement that broad and narrow DIBs define different subclasses (Herbig 1975, Jenniskens and Désert 1995). Although based on a much smaller statistical sample (11 stars), the correlation seems better in 4430/5780, 4430/6270, 4430/6284 (all "broad" DIBS) than in 4430/5797 or 4430/5850 (5797 and 5850 Å DIBs are narrow). We stress that the strong DIBs that correlate the best with the broadest DIB at 4430 Å are also quite broad. This observation could be an indication that two distinct populations of carriers exist (see section 4.3).

4.3. One strict correlation?

4.3.1. Intensity ratio

The strongest correlation found in our sample is between the two DIBs at 6614 and 6196 Å. They are also of similar FWHM: in average 2.6 and 1.7 cm^{-1} (1.14 and 0.65 Å). Fig. 4 shows the correlation between these two DIBs. For this case we also show the correlation using EW measurements to prevent any width or profile effect. Both CD and EW plots show a very strong correlation. Of the 62 measurements, only 4 deviate from the least-squared linear fit in CD, by more than 2σ. The correlation coefficient equals 0.97±0.14 and the cumulative probability curve is similar to the theoretical Kolmogorov curve (Fig. 4, bottom). Finally, the correlation coefficient of the EW plot is 0.98±0.18.

The lines of sight where the 6196/6614 ratio differs the most from the mean value are towards the stars HD164402, HD20041, HD43384. HD164402 presents strong and narrow stellar lines in its spectrum which blend interstellar features, so that this target may be a poor candidate to measure DIBs. HD20041 is the illuminating star of the reflection nebula VdB10 and, towards this line of sight, the bands are suprisingly broad. This could be an evidence of the rotational effect due to interactions between atomic and molecular gas close to the star (Rouan et al. 1997), thus implying that the DIB carrier are molecules. The EW correlation plot shows that this measurement is closer

to the best fitted line, which supports this interpretation. The opposite situation is observed for the star HD43384, towards which the DIBs are especially narrow. Also in that case, the EW correlation plot shows a better result. Towards the star HD183143, where we observe an effect averaged over several clouds, the ratio of the bands CD is close to the average whereas it is more discrepant from the average relation between EW. The reason is the multiple convolution of bands with various velocity fields, introducing an error in the EW estimation.

We carefully considered the case of Orion stars HD37020, HD37022, and HD37023. It has been observed previously that the DIB strengths in this cloud were anomalously weak with respect to the reddening (Jenninskens et al. 1993, Krełowski and Sneden 1993). We observe here that both 6196 and 6614 Å DIBs are weak towards these stars, and the 6614/6196 ratio is of the same order as the ratio in other targets. That means that the radiative conditions in the Orion cloud are such that the carrier(s) of 6196 and 6614 Å DIBs is(are) destroyed, either by fragmentation of its molecular skeleton or by change of its ionisation state (Sonnentrucker et al. 1997).

The conclusion of our observations is therefore that either the two DIBs originate from a single molecule, or that their carriers are very strongly linked, so that their abundances behave essentially the same regarding the interstellar conditions.

4.3.2. DIB profiles

In recent works based on high resolution spectroscopy of DIBs, a three peak substructure has been found in 6614 Å DIB (Sarre et al. 1995, Ehrenfreund and Foing 1996, Kerr et al. 1996). The 6196 Å DIB has been less extensively studied, but it seems to have a more symmetrical profile with a single component (Krełowski and Schmidt 1997). Is this apparent mismatch between the two profiles a strong point against a common carrier of the two bands? Not necessarily.

First we can consider the possibility that the three peak structure of 6614 Å is not an intrinsic profile, but an overlap of coincident features. Even if the interpretation of the profile in terms of rotational contours is very appealing in the context of molecular DIB carriers, it is nevertheless based on a sparse sample of heavily reddened stars. So the possibility exists that only one component over the three peaks is really correlated with 6196 Å. Our current data set is insufficient to address this issue.

Secondly, the DIB profiles depend on the internal couplings with other vibrational levels, and thus may not be the same for two distinct levels (Leach 1995). But this should be quite a marginal effect, because in the diffuse medium the ground level should be the most populated, and in any case, it would be an important test to search for profile variations of 6196 and 6614 Å DIBs in various lines of sight. Different profiles should indeed evolve in a similar way, if the bands have a common carrier. Such a critical test is necessary to confirm or deny the proposal of a unique carrier for the 6196 and 6614 Å DIBs.

The pair of bands 6196/6614 Å is thus one of the first examples of DIBs which could be related to a single species. Another pair of DIBs proposed to be carried by a single species are the 9577/9632 Å bands, measured in only a dozen lines of sight and tentatively attributed to C_{60}^{+} (Foing and Ehrenfreund 1994, 1997). However, the correlation between these two DIBs is far from being confirmed over a strong statistical basis. Moreover, Jenniskens et al. (1997) used a different method to remove telluric features, and did not conclude to the identification of C_{60}^{+}.

4.4. Comparisons with previous families

The first attempts to search for DIB correlations were based on small samples of stars, and aimed at observing common properties of DIBs versus color excess (Chlewicki et al. 1986, 1987). The three ”families” introduced by Krełowski and Walker (1987) gather bands where the intensity ratios are similar. Their work relies on poor statistics and thus could not evidence common DIB carriers, as expressed by Jenniskens and Désert (1995). We note that the 6196 and 6614 Å bands were not classified in the same family in this former work, while the correlation is very tight in

our much larger target sample. Our analysis supports the loose correlation observed by Krełowski and Walker (1987) between the pairs: 5797/5850 Å (also pointed out by Josafatsson and Snow (1987) in reflection nebulae), 5797/6614 Å, and 5850/6614 Å. For none of these three pairs is the correlation strict. On the other hand, we find that the 6379 Å DIB is not a member of the third family, as the correlation is weak with the other members.

A larger sample (26 stars) has been studied by Benvenuti and Porceddu (1989) who found some weak correlations between DIBs. Our results are in agreement with their conclusions for the bands that we both measured.

The classification of DIBs into narrow, broad and very broad features has already been proposed (Herbig 1975, Jenniskens and Désert 1995). It is also consistent with the "families" of Krełowski and Walker (1987). Besides the search for strict correlations and common carriers, we can confirm that DIBs of similar bandwidths correlate better with each other than do bands of different width. Although this statement does not offer a strong constraint for laboratory investigations on DIB carriers, it may suggest some interesting physical properties of the related species.

A recent study of DIB correlations has been published by Cami et al. (1997) which can be compared to our results. They adopted a statistical way of calculating the error bars; their correlation coefficients are therefore of different meaning. Also, they searched for correlations between a large number of DIBs assuming ionised carriers, and thus explored 13 lines of sight with particular properties. Our approach differs from theirs in the sense that we are probing the intrinsic spectroscopic properties of the carriers, without any *a priori* concept of their nature. Also our star sample is more extended and contains various types of clouds that allows better statistics. Cami et al. do not discuss the case for a strict correlation, between the DIBs at 6196 and 6614 Å. We agree with the "close species family" they propose, formed by the DIBs at 5797, 6379 and 6614 Å. We are unfortunately unable to discuss the other families proposed by Cami et al. as we did not measure band intensities when the signal-to-noise ratio was too low for reliable statistics.

In summary, we believe that our results offer an useful complement to previous searches for DIB families, because of the much larger sample of stars; the comparison is limited by the reduced number of common measured DIBs.

4.5. Implications

Let us consider the implications of our observations, regarding the most commonly invoked carbonaceous DIB carrier candidates: PAHs (polycylic aromatic hydrocarbons) and linear chains.

4.5.1. PAHs

PAH species have been proposed for 12 years as possible DIB carriers (Léger and d'Hendecourt 1985, Crawford et al. 1985, Léger 1995). Laboratory studies have shown that each open shell PAH (ions or radicals) possesses a dominant absorption band in the DIB range, and few weaker bands as vibrational sequences (Salama et al. 1996, d'Hendecourt et al., not published). The vibrational progression bands which could be correlated to the electronic origin are more likely characterized by a separation of 50 to ~ 3000 cm^{-1} and thus we may expect such sequences in the DIB spectrum. Unfortunately, they may be **too weak** to be easily detected in a large number of interstellar spectra, especially in moderately reddened stars. Some examples of very weak interstellar features related to stronger ones have been observed in a reduced number of lines of sight (Krełowski et al. 1997). A laboratory investigation of a derived perylene species has also led to meaningful observations, in terms of DIB profiles and sequences (Moutou et al. 1997).

In view of our results, we can firmly confirm that strong DIBs are not correlated in most cases; we did not measure weak DIBs as our spectra were not of sufficient signal-to-noise ratio and priority was given to a large set of targets.

The energy gap between the two correlated bands at 6196 and 6614 Å is 1019 cm^{-1}. If we would consider the DIB 6614 Å as an electronic ground state, then 6196 Å could be an excited

vibrational mode situated at 9.8 μm. This mode is compatible with known molecular vibrations and corresponds to a strong mode of aromatic molecules (not optically active in the infrared). This fact is obviously not an argument for claiming that the two DIBs are carried by aromatic species, but the unique carrier hypothesis is not in contradiction with the PAH hypothesis.

4.5.2. Unsaturated chains

Unsaturated carbon chains, as well, exhibit a strong origin followed by weaker bands (Fulara et al. 1993, Maier et al. 1995). A mixture of photon-resistant C_nH_m radicals and related ions could account for a fraction of the DIB spectrum, each species being responsible for approximately one to four bands. For the same reason as for PAHs, our observations are compatible with the DIB carriers being unsaturated carbon chains, and thus they do not allow to support the unsaturated chain model nor the PAH model, if one has to be prefered. Moreover, the number of possible linear molecules with the required robustness is probably too small to account for the whole spectrum, and the spectroscopy of both kinds of molecules should be more investigated in the future.

5. Conclusions

From this gathering of observations and DIB measurements we can extract a few conclusions which are of importance for the DIB classification into distinct families:

- The DIBs are correlated with E_{B-V} with a correlation coefficient close to 0.8; none of the DIB intensities can be precisely predicted from the E_{B-V} value.
- The two DIBs at 6614 and 6196 Å are strongly correlated. This is the only case in our sample where we can suggest a common carrier, this conclusion being carried by a statistical analysis over 62 lines of sight. However the question of their different profiles has to be clarified by further observation at high S/N and spectral resolution, where we could compare the variations of intrinsic profiles or bandwidths with respect to the physical properties.
- Some DIB pairs as 5797/5850, 6284/5780 Å are well-correlated, which is the evidence of species of close properties, but the DIBs originate from different carriers. This supports the previous tentative classification in narrow, intermediate and broad bands. However, this result is not strong as it does not constrain the laboratory search for potential carriers.
- The fact that in most cases the strong DIBs are not perfectly correlated indicates that their carriers produce usually a single strong feature; other features originating in these carriers are probably weaker. This result is compatible with the conclusions obtained by laboratory work on aromatic and linear carbonaceaous species (Salama et al. 1996, Fulara et al. 1993, Leach 1995). As a continuation of this work, we would stress the necessity of obtaining more measurements of weaker features and then try to retrieve the vibrational sequences that can be expected in the case of molecular carriers.

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Table 1. The list of target stars is given, including: the HD number, spectral type and luminosity class, the reddening E(B-V), the visual magnitude, rotational velocity (km/s).

HD	Sp T	E(B-V)	m_v	Vsini	HD	Sp T	E(B-V)	m_v	Vsini
					144217	B0.5 V	0.17	2.62	130
2905	B1 I	0.33	4.16	62	144470	B1 V	0.19	3.96	142
5394	B0 IV	0.10	2.47	300	145502	B3 V	0.25	4.01	199
8065	A0 I	0.39	6.46	–	147084	A4 III	0.96	4.55	15
10516	B2 V	0.17	4.07	450	147165	B2 III + O9.5 V	0.36	2.89	53
12953	A1 I	0.62	6.28	30	147933	B2 IV	0.44	5.02	303
13267	B5 I	0.41	6.36	53	148184	B2 IV	0.48	4.42	134
14489	A2 I	0.40	5.17	25	149757	O9.5 V	0.29	2.56	379
20041	A0 I	0.73	5.79	–	154445	B1V	0.39	5.64	174
21291	B9 I	0.42	4.21	29	163472	B2 IV-V	0.30	5.82	120
21389	A0 Iae	0.56	4.54	6	164284	B2 Ve	0.18	4.64	221
22951	B0 V	0.23	4.97	51	164353	B5 Ib	0.23	3.97	22
23180	B1 III	0.26	3.82	85	164402	B0 I	0.22	5.77	100
24398	B1 Ib	0.31	2.85	59	166182	B2 IV	0.04	4.36	-
24534	O9.5pe	0.56	6.10	150	166937	B8 I	0.34	3.86	54
24760	B0.5 V + A2 V	0.06	2.89	153	170740	B2 V	0.45	5.72	-
24912	O7.5 III	0.29	4.02	216	179406	B3 V	0.31	5.34	187
25204	B3 V + A4 IV	0.30	3.47	75	183143	B7 Iae	1.28	6.86	59
34078	O9.5 V	0.50	8.00	5	184915	B0.5 III	0.22	4.95	259
37020	B3 V	0.37	6.36	112	193237	B2 pe	0.61	4.81	75
37022	B8 III	0.96	8.31	127	198478	B3 Iae	0.54	4.84	35
37023	O9.5 Iae	0.26	4.29	109	199478	B8 I	1.00	5.67	-
37042	B1 V	0.32	6.39	-	199579	O6 Ve	0.34	5.96	170
37061	B1 V	0.50	6.82	-	202850	B9 Iab	0.13	4.23	28
40111	B0.5 II	0.28	4.76	130	202904	B2 V	0.10	4.43	261
41117	B2 Ia	0.44	4.63	36	203064	O8 e	0.28	5.00	328
41335	B2 V	0.15	5.21	419	206165	B2 Ib	0.46	4.73	36
42087	B2.5 I	0.35	5.75	37	206267	O6f	0.50	5.62	154
43384	B3 I	0.58	6.25	51	207198	O9 II	0.56	5.95	76
45725	B3 V	0.08	4.60	346	207260	A2Ia	0.50	4.29	33
48099	O6 e	0.34	6.37	–	208501	B8Ib	0.75	5.80	53
47129	O8 V	0.33	6.06	80	209481	O9 V	0.34	5.56	130
47240	B1 I	0.33	6.15	126	209975	O9 I	0.33	5.11	33
54662	O7 III	0.27	6.21	91	210839	O6 If	0.46	5.04	285
89353	B9.5 I	0.24	5.34	–	212076	B2 IV	0.08	5.01	134
141637	B3 V	0.13	4.64	300	213420	B2 IV	0.16	5.95	–
142096	B3 V	0.20	5.02	207	216200	B3 IV	0.25	5.92	225
142114	B2.5 V	0.12	4.59	308	218376	B0.5 IV	0.21	4.85	50
142184	B2.5 V	0.15	5.42	349	223128	B2 IV	0.16	5.95	–
143275	B0.5 IV	0.12	2.32	181	224572	B1 V	0.16	4.88	189

Table 2. List of DIB measurements. For each star of the sample, the central depths and standard errors are given in %. The uncertainty (in parenthesis) is estimated by multiple measurements. "-" means that the measurement is not possible, either because of band weakness or lack of data.

HD	4430	5780	5797	5850	6196	6234	6270	6284	6379	6614
2905		13.4 (0.3)	8.5 (0.4)	2.3 (0.1)	7.0 (0.5)	-	-	-	8.6 (0.3)	11.9 (0.5)
5394		1.8 (0.2)	1.6 (0.3)	0.6 (0.2)	0.9 (0.4)	-	-	-	6.5 (0.4)	1.2 (0.8)
14489		14.7 (0.4)	7.3 (0.3)	3.0 (0.1)	5.0 (0.4)	-	-	-	5.6 (0.4)	9.7 (0.3)
20041		20.2 (0.4)	13.0 (0.9)	4.6 (0.3)	9.3 (0.8)	-	-	-	12.5 (1.3)	22.4 (1.9)
21291		9.9 (0.2)	7.4 (0.4)	3.1 (0.2)	4.9 (0.5)	-	-	-	5.6 (0.2)	9.6 (0.5)
21389		19.0 (0.3)	8.9 (0.6)	3.1 (0.2)	7.4 (0.5)	-	-	-	7.6 (0.9)	15.0 (0.6)
23180		4.2 (0.2)	8.1 (0.6)	4.6 (0.2)	3.4 (0.2)	-	-	-	7.0 (0.8)	4.5 (0.3)
22951		5.0 (0.2)	4.4 (0.2)	1.9 (0.1)	3.8 (0.2)	-	-	-	3.2 (0.3)	5.9 (0.3)
24398		5.0 (0.3)	7.4 (0.6)	3.1 (0.4)	4.1 (0.1)	-	-	-	8.9 (0.8)	6.2 (0.2)
24912		9.4 (0.3)	5.1 (0.3)	2.1 (0.1)	4.6 (0.2)	-	-	-	5.1 (0.7)	7.4 (0.5)
37020		2.4 (0.4)	1.1 (0.3)	1.0 (0.2)	1.3 (0.4)	-	-	-	1.3 (0.4)	1.3 (0.6)
37022		3.0 (0.4)	1.0 (0.3)	0.7 (0.4)	1.3 (0.3)	-	-	-	1.1 (0.3	1.2 (0.3)
37023		2.8 (0.4)	1.4 (0.3)	1.0 (0.2)	1.4 (0.2)	-	-	-	1.4 (0.2)	1.3 (0.1)
34078		8.1 (0.4)	5.6 (0.3)	2.3 (0.3)	3.7 (0.3)	-	-	-	2.2 (0.3)	4.8 (0.5)
41117		16.0 (0.2)	14.0 (0.6)	5.6 (0.3)	8.3 (0.3)	-	-	-	16.3 (1.7)	15.6 (0.7)
42087		11.7 (0.3)	10.6 (0.8)	5.6 (0.3)	6.5 (0.4)	-	-	-	7.6 (0.3)	11.5 (0.9)
43384		20.7 (0.5)	14.1 (0.9)	5.0 (0.2)	11.2 (1.1)	-	-	-	12.1 (1.5)	19.1 (1.2)
41335		1.4 (0.1)	1.3 (0.1)	0.8 (0.1)	2.1 (0.3)	-	-	-	1.3 (0.2)	3.2 (0.3)
89353		1.7 (0.3)	1.3 (0.1)	1.1 (0.2)	1.0 (0.2)	0.5 (0.2)	1.3 (0.1)	1.2 (0.2)	1.1 (0.2)	0.7 (0.3)
141637		4.2 (0.1)	1.2 (0.1)	1.1 (0.3)	1.8 (0.1)	0.7 (0.1)	1.9 (0.2)	3.7 (0.4)	1.6 (0.1)	2.1 (0.3)
142114		3.5 (0.2)	1.2 (0.1)	0.7 (0.1)	1.7 (0.1)	0.4 (0.1)	1.4 (0.1)	3.1 (0.5)	1.5 (0.1)	1.4 (0.1)
143275		9.8 (0.3)	2.0 (0.1)	1.0 (0.1)	1.9 (0.2)	0.5 (0.1)	1.2 (0.1)	3.0 (0.3)	1.6 (0.1)	1.5 (0.1)
144470		0.9 (0.1)	3.2 (0.2)	1.3 (0.2)	3.9 (0.3)	1.3 (0.1)	2.1(0.3)	4.6 (0.2)	4.2 (0.1)	6.4 (0.3)
145502	5.7(0.6)	8.5 (0.2)	3.8 (0.2)	1.5 (0.1)	3.2 (0.1)	1.3 (0.2)	1.1 (0.3)	5.7 (0.2)	4.6 (0.2)	6.0 (0.3)
147165		12.0 (0.5)	3.6 (0.1)	1.6 (0.3)	3.7 (0.1)	1.6 (0.2)	1.3 (0.3)	5.1 (0.2)	4.0 (0.2)	5.7 (0.3)
147933		10.1 (0.2)	6.7 (0.1)	2.9 (0.5)	3.4 (0.3)	1.2 (0.2)	1.2 (0.2)	3.6 (0.4)	4.0 (0.1)	5.2 (0.3)
148184		5.5 (0.3)	5.3 (0.2)	3.4 (0.2)	2.4 (0.2)	1.2 (0.2)	1.1 (0.2)	2.8 (0.3)	4.2 (0.2)	4.2 (0.5)
149757	3.7 (0.4)	3.7 (0.1)	4.1 (0.1)	1.9 (0.1)	2.5 (0.1)	1.0 (0.2)	1.1 (0.1)	2.0 (0.1)	3.5 (0.2)	3.4 (0.1)
154445	4.7(0.5)	9.7 (0.3)	7.9 (0.5)	2.8 (0.2)	5.7 (0.5)	1.8 (0.2)	3.1 (0.3)	4.1 (0.3)	7.8 (0.2)	11.8 (0.9)
164402		7.2 (0.4)	4.4 (0.2)	2.6 (0.3)	4.0 (0.4)	1.2 (0.1)	1.6 (0.1)	3.0 (0.1)	3.8 (0.1)	4.0 (0.5)
166937		12.3 (0.5)	9.2 (0.6)	3.8 (0.5)	5.7 (0.5)	1.7 (0.2)	3.3 (0.2)	8.1 (0.2)	8.3 (0.2)	9.4 (0.4)
179406		8.2 (0.3)	8.4 (0.6)	4.1 (0.2)	4.8 (0.1)	1.3 (0.4)	2.8 (0.2)	2.7 (0.2)	9.7 (0.4)	9.0 (0.4)
184915	5.9 (0.6)	7.6 (0.2)	3.1 (0.2)	1.1 (0.1)	4.4 (0.1)	0.8 (0.2)	2.6 (0.3)	3.6 (0.3)	3.8 (0.2)	6.9 (0.6)
198478	6.7(0.7)	14.2 (0.9)	9.0 (0.6)	3.6 (0.2)	7.0 (0.2)	2.1 (0.1)	3.9 (0.4)	3.9 (0.5)	9.5 (0.1)	12.4 (0.6)
199579		5.4 (0.3)	5.5 (0.5)	2.6 (0.2	3.2 (0.2)	2.0 (0.3)	1.2 (0.1)	3.68 (0.4)	2.9 (0.3)	4.8 (0.6)
203064		7.7 (0.3)	5.5 (0.5)	2.4 (0.4)	3.7 (0.2)	1.6 (0.2)	2.0 (0.2)	6.0 (0.6)	2.9 (0.2)	6.7 (0.6)
206165	5.9 (0.6)	9.5 (0.9)	8.9 (0.2)	3.8 (0.4)	5.6 (0.2)	1.4 (0.1)	2.9 (0.3)	6.8 (0.7)	8.4 (0.1)	10.5 (0.5)
206267		10.3 (0.2)	9.9 (0.4)	4.5 (0.3)	6.2 (0.5)	2.1 (0.3)	3.1 (0.3)	7.1 (0.7)	6.2 (0.3)	11.3 (0.5)
207260	5.9 (0.6)	14.8 (0.4)	11.0 (0.9)	4.0 (0.2)	7.0 (0.7)	1.8 (0.2)	4.9 (0.5)	9.3 (0.9)	11.5 (0.2)	13.6 (0.8)
208501	5.2 (0.5)	10.9 (0.3)	11.0 (0.9)	3.8 (0.3)	6.5 (0.4)	2.0 (0.3)	3.5 (0.4)	6.7 (0.8)	8.5 (0.3)	11.8 (0.5)
210839		11.4 (0.4)	9.6 (0.6)	3.1 (0.2)	7.4 (0.4)	1.9 (0.1)	5.2 (0.5)	7.5 (0.8)	8.4 (0.1)	14.3 (0.4)
209975		11.8 (0.3)	8.7 (0.2)	3.3 (0.2)	6.2 (0.2)	2.0 (0.1)	3.8 (0.4)	8.0 (0.8)	7.2 (0.1)	11.6 (0.7)
54662		9.5 (0.3)	6.3 (0.3)	2.8 (0.3)	4.5 (0.3)	1.6 (0.5)	3.3 (0.4)	8.8 (0.9)	5.2 (0.5)	8.8 (0.6)
207198		11.1 (0.2)	16.0 (1.2)	8.5 (0.3)	6.7 (0.2)	2.7 (0.1)	3.9 (0.4)	7.9 (0.8)	11.8 (0.3)	12.6 (0.9)
209481		8.5 (0.4)	6.8 (0.8)	2.9 (0.4)	5.1 (0.1)	1.5 (0.4)	3.5 (0.4)	6.8 (0.7)	11.8 (0.4)	9.6 (0.7)
24534	2.5 (0.3)	4.6 (0.2)	7.5 (0.4)	4.4 (0.6)	3.8 (0.2)	1.8 (0.3)	2.0 (0.2)	3.5 (0.5)	7.4 (0.3)	5.8 (0.5)
212076		1.7 (0.4)	1.6 (0.2)	0.8 (0.2)	1.3 (0.1)	0.8 (0.2)	2.0 (0.2)	2.0 (0.2)	1.5 (0.2)	1.3 (0.2)
218376		5.9 (0.3)	4.8 (0.2)	1.8 (0.2)	3.6 (0.2)	1.1 (0.2)	2.9 (0.3)	5.1 (0.5)	5.5 (0.3)	6.5 (0.4)
223128		6.4 (0.4)	6.3 (0.3)	2.4 (0.4)	3.8 (0.2)	1.1 (0.2)	2.8 (0.3)	4.8 (0.5)	5.5 (0.2)	6.6 (0.3)
47129		8.2 (0.4)	5.1 (0.3)	1.8 (0.5)	4.2 (0.2)	0.6(0.2)	5.0(0.5)	6.7(0.7)	5.1 (0.2)	8.1 (0.5)
47099		8.8 (0.4)	0.1 (0.1)	5.4 (0.3)	3.9 (0.2)	-	-	-	3.4 (0.5)	8.7 (0.4)
37061		6.8 (2.0)	1.6 (0.1)	0.9 (0.2)	1.6 (0.4)	-	-	-	1.8 (0.5)	1.6 (0.1)
37042		1.9 (0.1)	0.9 (0.2)	0.7 (0.1)	0.9 (0.2)	-	-	-	1.8 (0.1)	1.8 (0.2)
47240		11.2 (0.9)	8.4 (0.6)	3.4 (0.3)	5.7 (0.6)	-	-	-	7.4 (0.7)	10.9 (0.9)
224572		3.6 (0.2)	2.8 (0.2)	1.5 (0.3)	2.2 (0.2)	-	-	-	1.7 (0.2)	4.0 (0.3)
213420		4.1 (0.1)	2.6 (0.1)	1.6 (0.1)	1.9 (0.2)	-	-	-	1.7 (0.1)	3.5 (0.2)
216200		4.6 (0.5)	5.3 (0.5)	2.6 (0.2)	2.2 (0.1)	-	-	-	2.7 (0.1)	4.3 (0.1)
144217	7.7 (0.8)	8.4 (0.2)	2.2 (0.1)	0.7 (0.2)	3.0 (0.2)	-	-	-	2.5 (0.3)	5.3 (0.6)

Table 3. Correlation coefficients: [a] : sample of 62 stars, [b] : sample of 36 stars, [c] : sample of 11 stars.

	4430[c]	5780	5797	5850	6196	6234[b]	6270[b]	6284[b]	6379
6614[a]	0.35 (0.015)	0.93 (0.12)	0.91 (0.13)	0.77 (0.14)	0.97 (0.14)	0.62 (0.15)	0.70 (0.08)	0.67 (0.08)	0.88 (0.13)
6379[a]	0.26 (0.02)	0.78 (0.09)	0.92 (0.11)	0.84 (0.14)	0.90 (0.11)	0.60 (0.12)	0.58 (0.05)	0.54 (0.05)	
6284[b]	0.39 (0.02)	0.69 (0.06)	0.59 (0.05)	0.47 (0.06)	0.67 (0.06)	0.48 (0.10)	0.71 (0.07)		
6270[b]	0.38 (0.03)	0.66 (0.06)	0.61 (0.05)	0.47 (0.06)	0.70 (0.06)	0.45 (0.10)			
6234[b]	0.22 (0.02)	0.52 (0.11)	0.67 (0.13)	0.65 (0.16)	0.62 (0.13)				
6196[a]	0.36 (0.02)	0.93 (0.10)	0.92 (0.11)	0.79 (0.12)					
5850[a]	0.22 (0.02)	0.68 (0.10)	0.93 (0.14)						
5797[a]	0.29 (0.01)	0.83 (0.09)							
5780[a]	0.39 (0.02)								

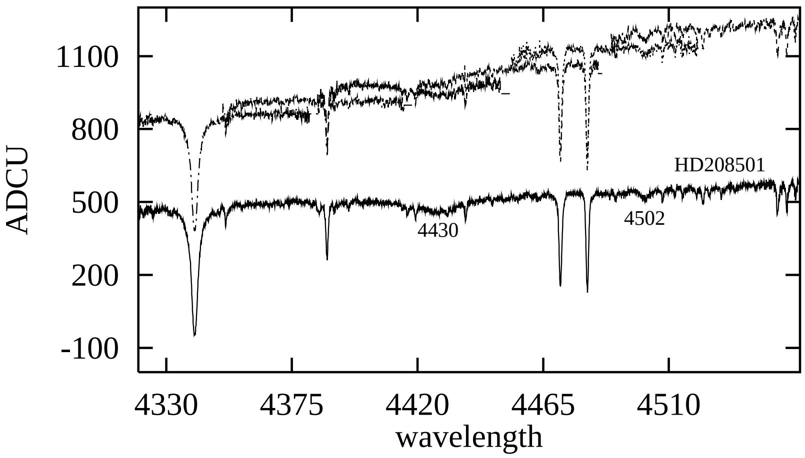

Fig. 1. The spectrum of HD208501 containing the 4430 and 4502 Å diffuse bands, obtained with MUSICOS in July 1995. Wavelengths are in Å, while flux values are in arbitrary units. The six orders (top) are merged into one spectrum (bottom). Note the flatness of the continua in individual orders. Narrow lines are of stellar origin.

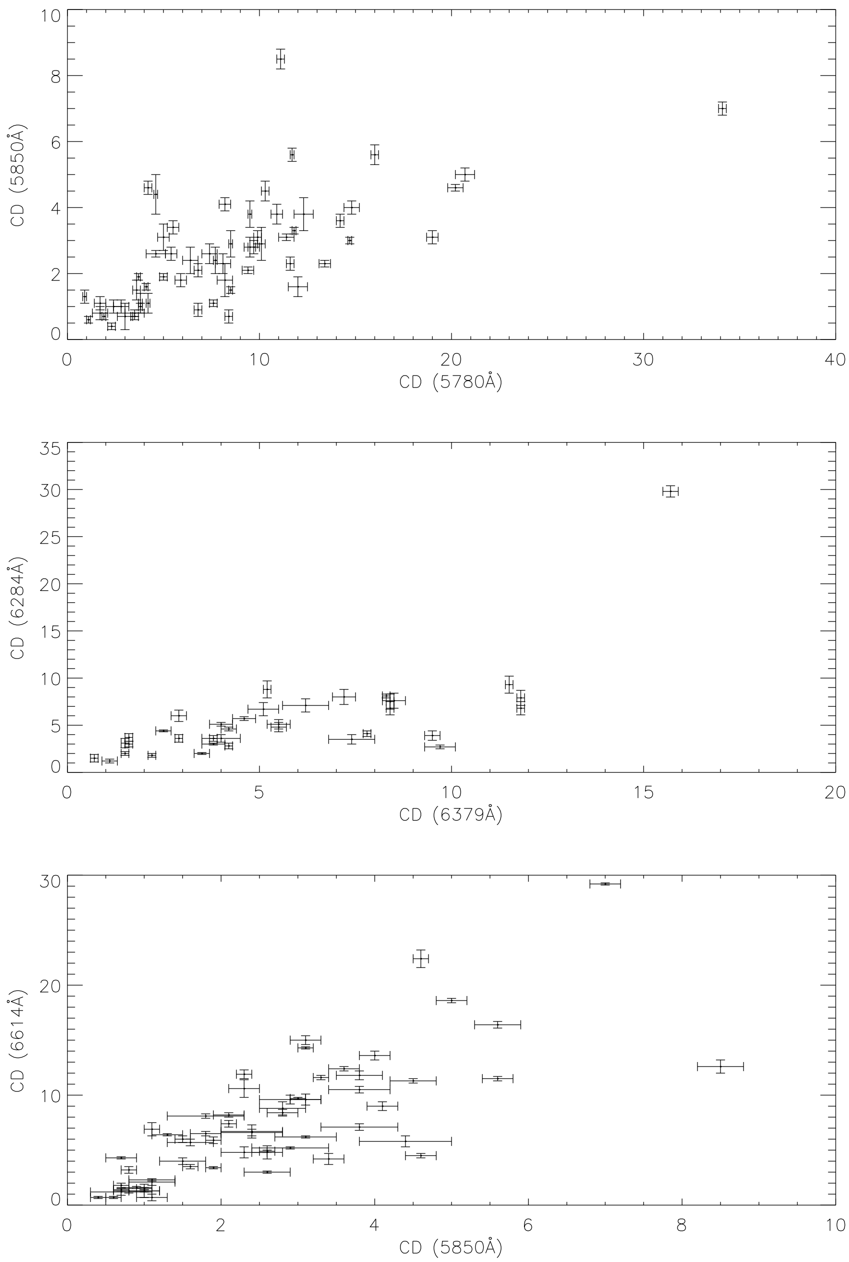

Fig. 2. The correlation plots between some pairs of measured DIBs, when the correlation is very poor. The high dispersion indicates different origins. CD are in % of the continuum.

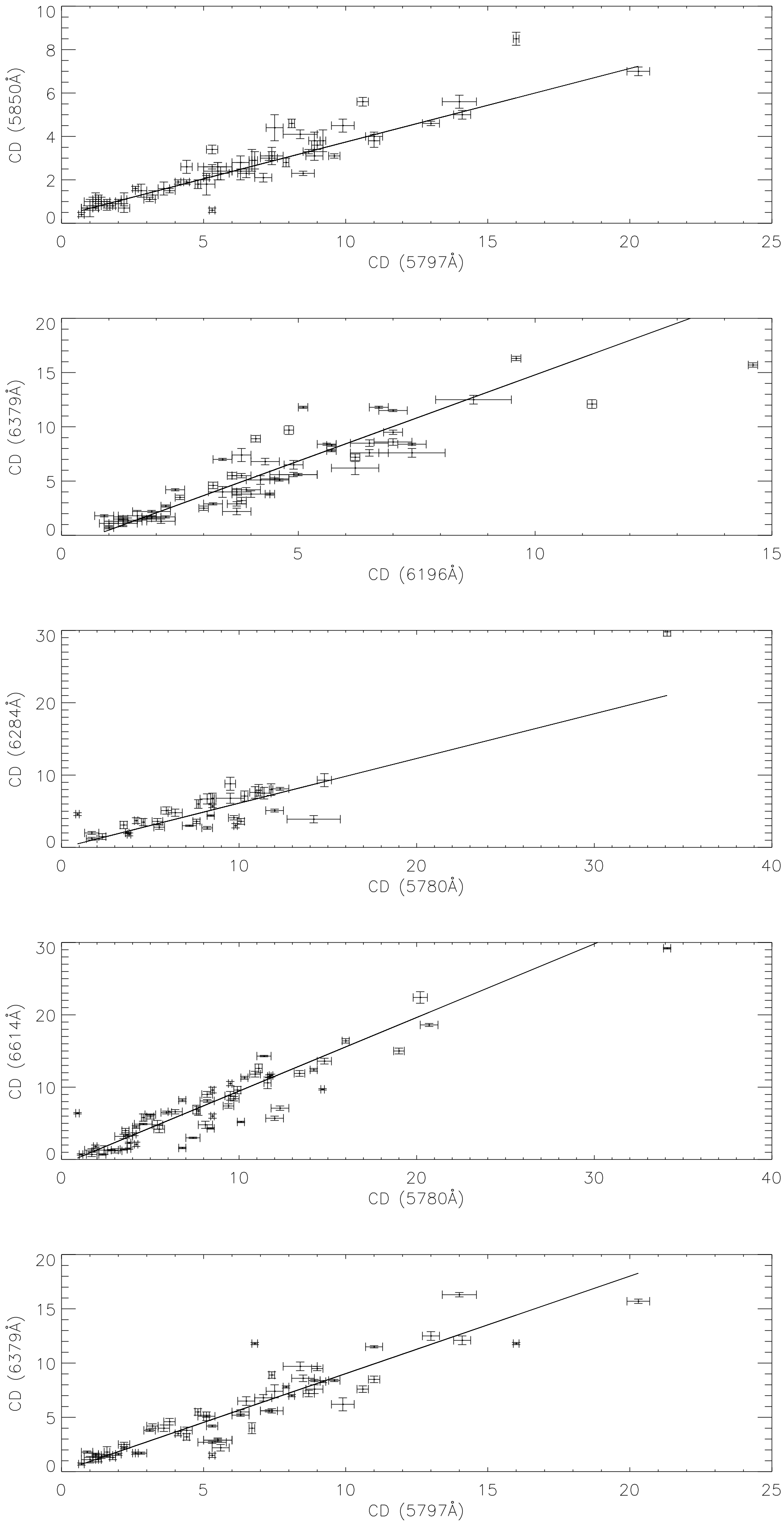

Fig. 3. The correlation plots between some pairs of measured DIBs, when the correlation is rather good. The least-squared linear curve is also plotted. In each plot some points obviously deviate from the fit by more than 3σ, excluding the possibility of a common carrier.

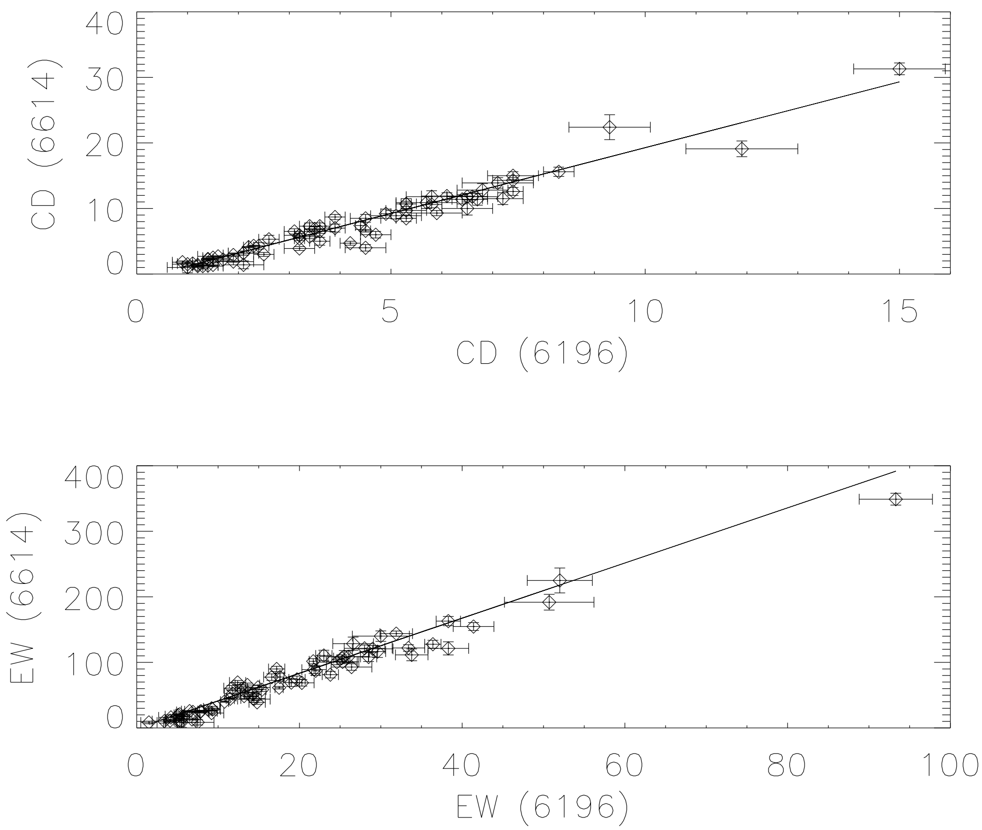

Fig. 4. The correlation plot between DIBs at 6614 and 6196 Å in 62 lines of sight. We show both the central depth (CD in %) and the equivalent width (EW in Å) correlation plots. The difference between the two plots is weak and concerns mostly the most reddened objects for which the bandwidth is the most sensitive to averaging between different clouds. The EW correlation nevertheless shows a lower dispersion.